Parameterizing Internal Wave and Boundary Mixing in a Canyon
(AESOP Internal Waves and Boundary Mixing)

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LONG-TERM GOALS

This project in collaboration with Eric Kunze at the University of Victoria aims to increase our understanding of internal wave processes affecting diapycnal mixing in the ocean, with the ultimate goal of improving mixing parameterizations in numerical models.

OBJECTIVES

- To characterize the full water-column structure of the internal wave field in a region of coherent internal tides.
- To test numerical predictions of internal tide generation and propagation.
- To estimate rates of internal wave spectral energy transfer through critical reflection, topographic generation, and boundary and internal dissipation.
- To estimate bottom boundary layer mixing and its effect on internal wave energy budgets and interior stratification.
- To compare mixing estimates with diffusivities and turbulent fluxes from regional numerical models with a view toward determining the impact of internal waves on simulated distributions of temperature and salinity.
- To use this information to guide improvements in mixing parameterizations, leading to improved predictions of oceanic properties and air-sea fluxes.

APPROACH

Our approach is to use tide-resolving surveys and timeseries with a variety of profiling instruments to develop a picture of the 3-D structure of the internal tide and accompanying energy flux and dissipation. Estimates of the along-slope and cross-slope fluxes and gradients, together with wavenumber content will allow validation of numerical models predicting topographic generation of internal tides on the continental slope near Monterey Bay. In addition, dissipation and energy flux measurements will allow estimates of boundary mixing and spectral transfer due to critical reflection,

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and a few high-frequency timeseries aim to characterize rapid variability in the form of non-linear surface and bottom boundary layer internal waves/bores.

Profiling instruments used include the XCP (expendable current profiler), a rapid-surveying tool providing a full water column (up to 2000 m) profile of temperature and instantaneous horizontal water velocity; VMP (vertical microstructure profiler) a loosely-tethered profiler capable of making hourly profiles of T, S and turbulent dissipation to 1000 m, depending on wind and sea state; EM-POGO, a low-cost free-falling, recoverable, full-water column velocity and temperature profiler; CTD/LADCP (a single 300 KHz Workhorse ADCP mounted on the *Point Sur*'s CTD package), providing full water column measurements of T, S and water velocity, as well as dissolved oxygen, chlorophyll fluorescence, and light transmission; and finally the vessel-mounted 75 KHz ADCP (acoustic Doppler current profiler), returning profiles of water velocity to 400 m or greater (typically in 5-min averages).

Note that, contrary to the original title of our project, the measurement focus was not the canyon, but rather a more generic continental slope location selected on the basis of numerical predictions by the various modeling groups involved in the MB06 experiments. Since several models agreed that a submarine ridge west of Point Sur (36°18’N) was a generation site for internal tides propagating northward into Monterey Canyon (Kunze et al 2002), the AESOP investigators decided to site the observational component of the experiment over the continental slope west of Point Lobos, within the internal tide beam between the ridge and the canyon (Figs. 1 and 2).

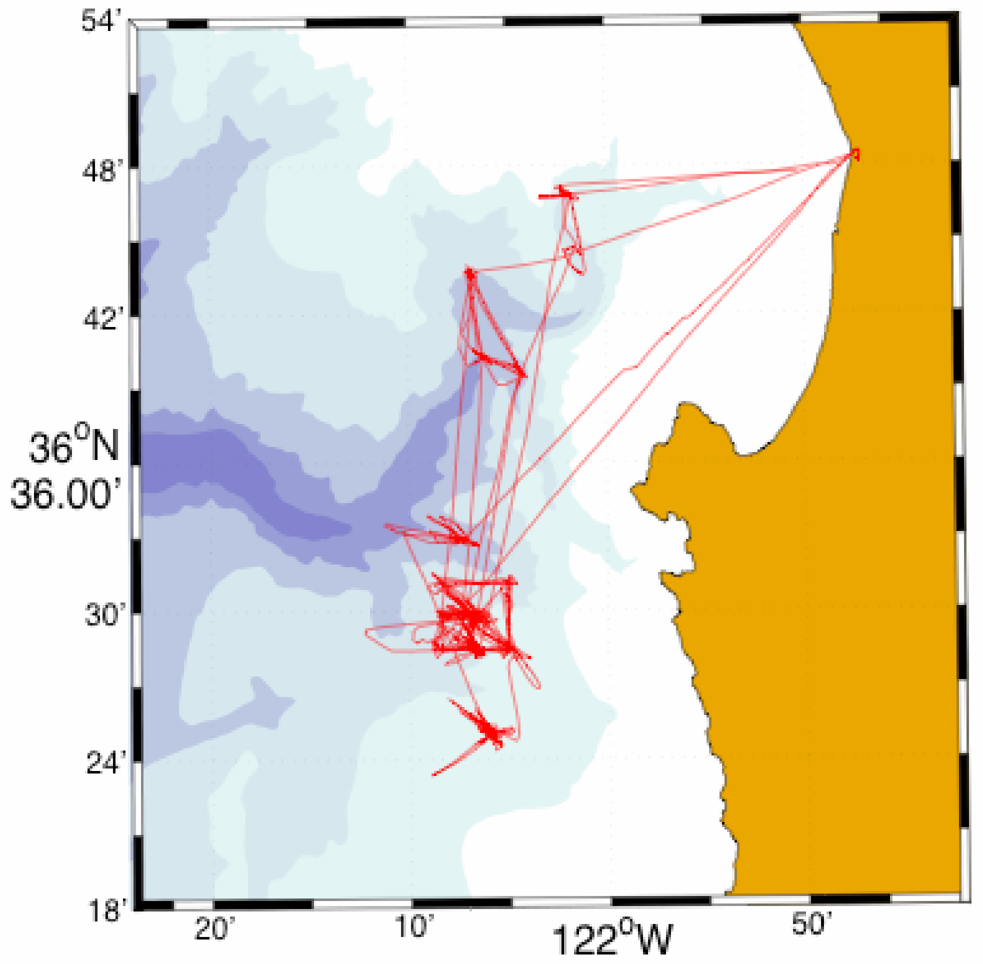

Figure 1: Cruise track for the R/V Point Sur during the 10-day experiment, illustrating the primary station locations and routes to and from the port (Moss Landing, CA) at the head of the canyon. Note that some profiling operations, especially the VMP, but also to some extent the CTD, resulted in substantial departure of the ship from the nominal station positions.

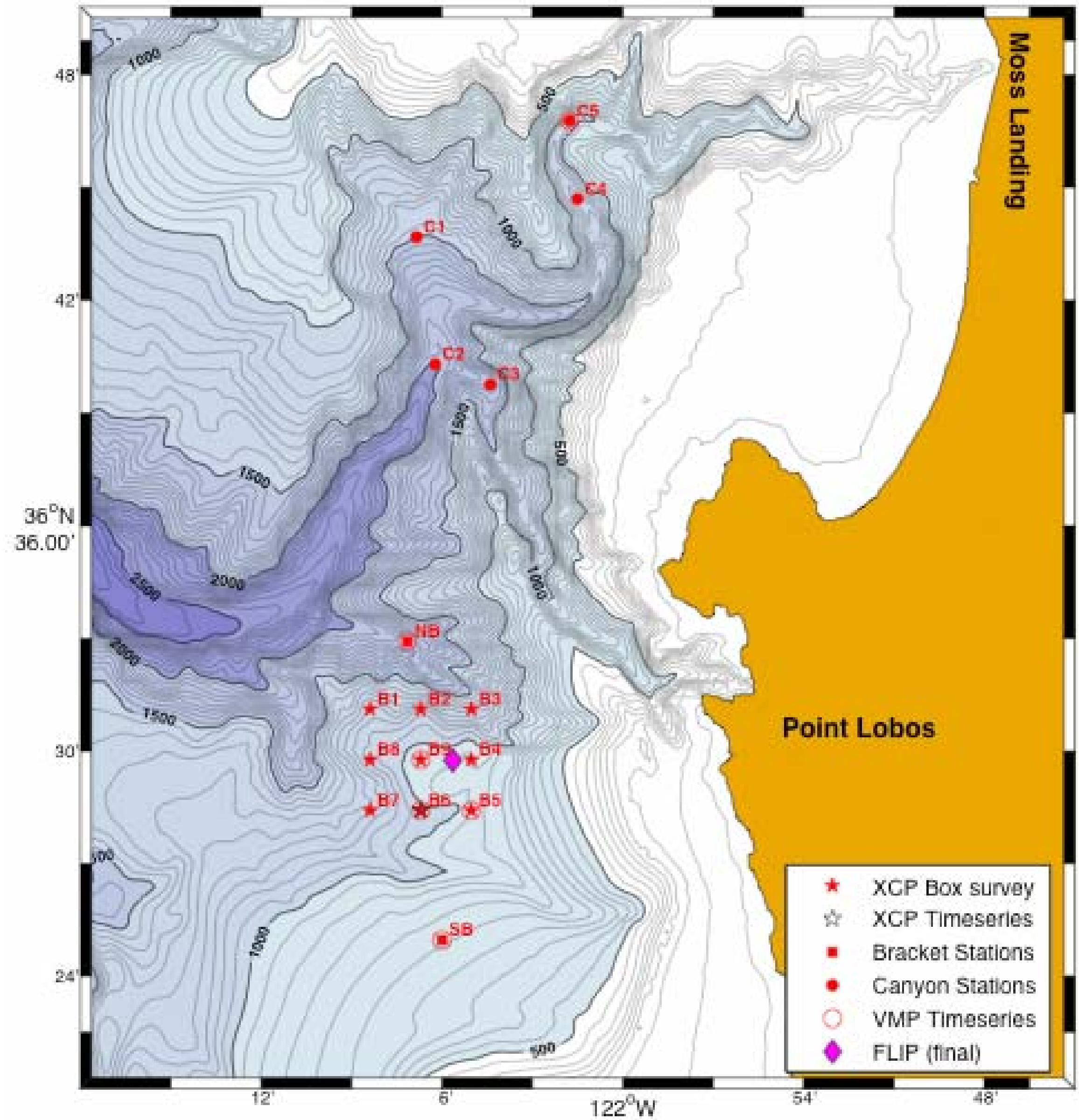

Figure 2: Nominal stations (waypoints) occupied during the R/V Point Sur cruise. A complete tide-resolving timeseries of (at a minimum) full-depth velocity and temperature was obtained at all stations except for the northern "bracket" (NB) which only received 3 hours of velocity profiles. Most attention was focused on the "XCP box" stations (red stars) occupied Aug 14 and 15. Station B6 was also the site of a high-resolution timeseries on Aug 16. The diamond indicates the location where FLIP was moored on Aug 18.

WORK COMPLETED

The field experiment was conducted during a 10-day cruise on the R/V *Point Sur* (10–19 August 2006) concurrent with several other cruises making up the AESOP field experiment in Monterey Bay. A full description of the activities can be found in the cruise report, available online at http://charybdis.apl.washington.edu/aesop/cruisereport.pdf. A brief summary is as follows:

- A 3x3 grid ("box") of XCP profiles (red stars in Fig. 2), occupied 5 times over semidiurnal tidal cycles on two consecutive days, sampled the full range of tidal phase, allowing a 3-D picture of the internal wavefield to be constructed.

- An additional high-resolution (half-hourly) XCP timeseries was made at one of the box stations on the following day (black star in Fig. 2).

- CTD/LADCP and EM-POGO timeseries were collected at sites bracketing the box to the north and south, as well as in a few stations at the mouth and interior of Monterey Canyon (filled circles and squares in Fig. 2).

- 12-hour VMP timeseries were collected each night (open circles in Fig. 2).

- Under-way meteorological and near-surface oceanographic data were collected along the entire cruise track (Fig. 1).

RESULTS

Analysis of the full data set has only just begun, so the primary result is simply that all instrumentation worked sufficiently well to return the planned measurements in a sampling pattern that allows extraction of the semidiurnal tide at all sites. Sample individual profiles from the XCP, CTD and LADCP are shown in Figs. 3, 4, and 5, respectively. In addition, the full set of XCP velocity profiles at each of the "box" stations is shown in Fig. 6.

Though the measurement program was indeed successful, it must be pointed out that clear patterns in the internal tides do not exactly jump out of initial examinations of the data (with the possible exception of the canyon stations, where strong dissipation and tidal velocities were seen). Initial conclusions from the box profiles (Fig. 6) are that (a) low-mode tidal variability only appears at a few of the box stations (possibly B5 and B6), (b) significant mean (i.e., sub-tidal frequency) shear is seen in many of the box stations, with a strong degree of coherence across the box and a general agreement with flow patterns (a near-surface southward-flowing jet overlying the broad northward flow of the California Undercurrent) seen in NCOM simulations for the period of the measurements. It is hoped that a coherent internal tidal signal will be evident once the planned harmonic analyses have been completed, but if the apparently large horizontal variability on the scale of the XCP box survey and predominantly high-mode structure remain, this will present a serious challenge to the modeling groups involved in the AESOP project.

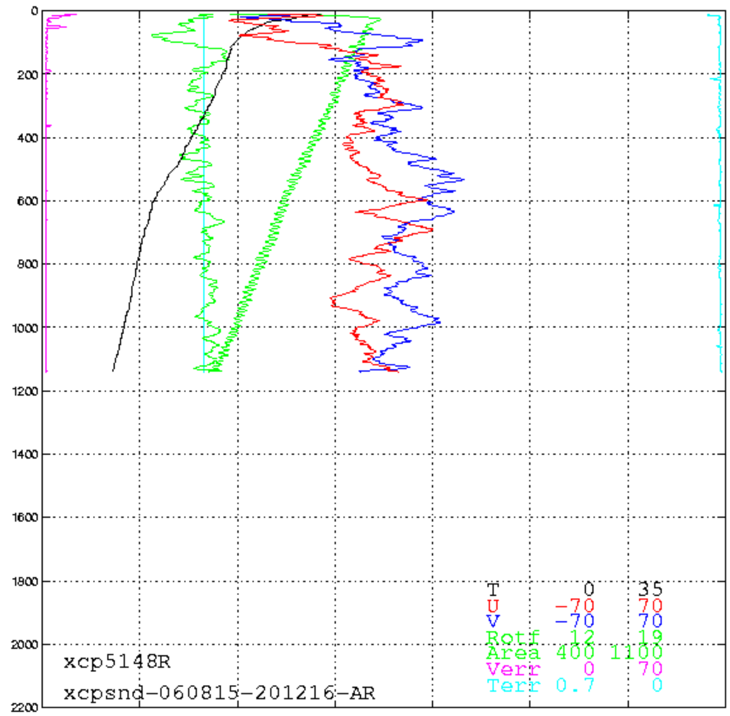

Figure 3: XCP profile from B1, the northwestern "box station." The velocity components have not been made absolute through referencing to the shipboard ADCP.

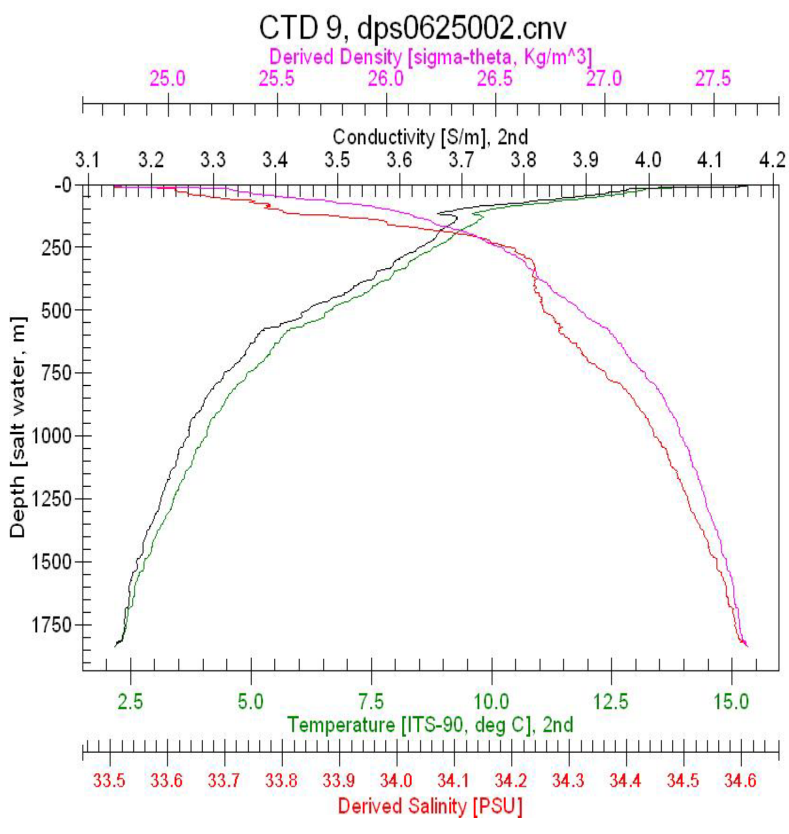

Figure 4: Sample CTD profile from the northern "bracket station."

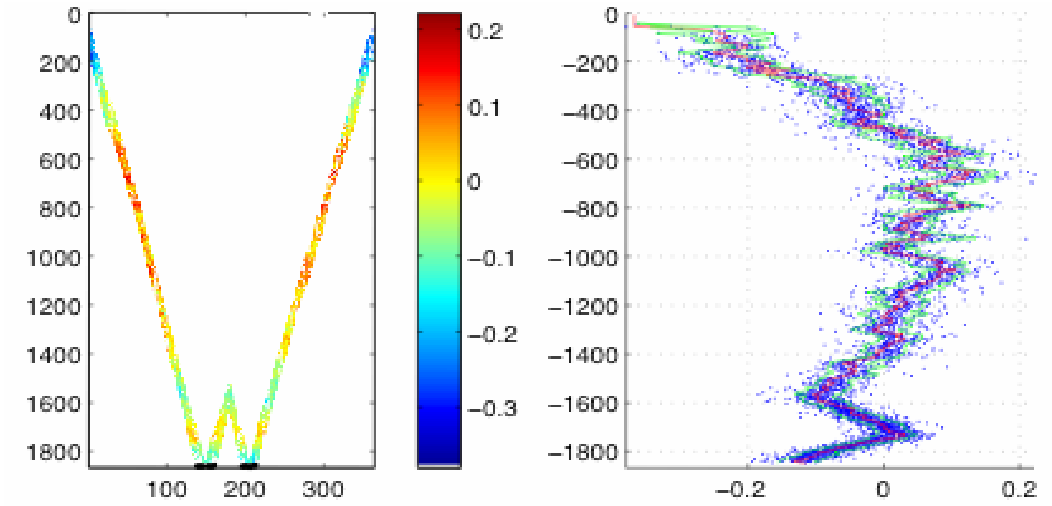

Figure 5: Sample LADCP profile of east–west velocity from the northern "bracket station." The left-hand panel illustrates the LADCP concept, showing all of the velocity data acquired (a 100 m swath beneath the CTD package) in depth (m) vs. time (units about 15 s in length). Color indicates velocity in m/s after subtracting the package motion. Horizontal "banding" demonstrates the validity of a key LADCP assumption—that the velocity profile is not changing rapidly in time. The right-hand panel shows the final absolute velocity profile (using bottom-tracking information) both as single-ping data (dots) and as a more robust low-passed profile. On this profile the CTD package made a single yo-yo over the bottom 300m, resulting in the "W" shape in the time-depth plot.

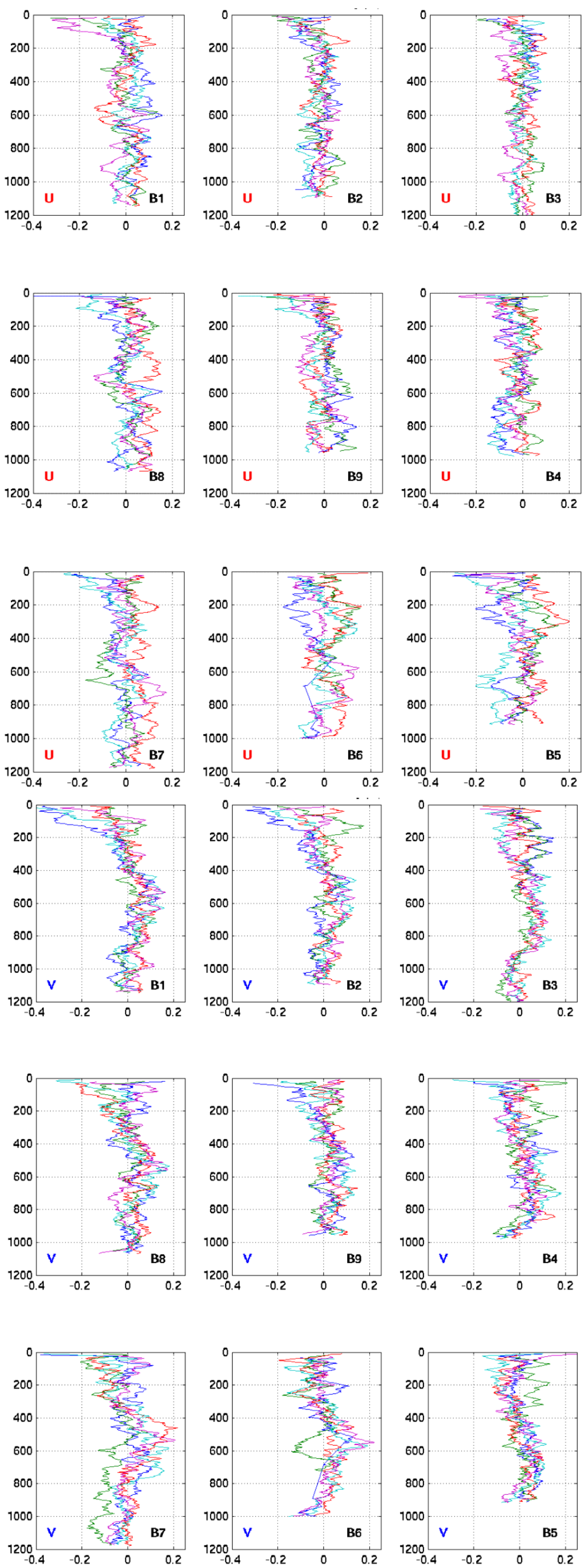

Figure 6: All XCP velocity profiles from the 3x3 box survey, plotted by station (B1–B9) and component (U=east, V=north). Significant variability (mostly tidal) and mean shear are present.

IMPACT/APPLICATIONS

Our work is expected to add significantly to the knowledge of the internal wave field, its interactions with topography, and implications for mixing of tracers and momentum. Both the wavefield and the topographic interactions are generally not well-represented in numerical models, resulting in a great degree of uncertainty over appropriate mixing coefficients or parameterizations. Our measurements will permit validation of existing parameterizations in a small highly-resolved region, as well as aid in the development of new parameterizations.

RELATED PROJECTS

Our work has been closely coordinated with the activities of other investigators in the AESOP DRI. In particular, high-frequency measurements from FLIP (Klymak, Pinkel) and regional surveys with SeaSoar (Johnston, Rudnick) help set the temporal and spatial context for our concentrated surveys. Initial results (Jachec et al 2006) from high-resolution modeling efforts by the SUNTANS group (Fringer, Street, Jachec) were instrumental in guiding the final placement of resources in the field program. In the analysis stages, we plan to work closely with these regional modelers on mixing and internal wave validation, as well as with high-resolution process modelers (MacKinnon, Sarkhar, Taylor) on wave-wave interactions and boundary layer processes. In addition, our measurements contributed data to the regional model assimilations being run as part of the ASAP experiment, including NCOM (Shulman), ROMS (Wang) and HOPS (Lermusiaux), and our pre-experiment planning took advantage of initial results from tide-resolving simulations being run by each of these groups.

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